Reflector antenna design in different frequencies using frequency selective surfaces

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ABSTRACT

In this study, it is aimed to obtain two different asymmetric radiation patterns obtained from antennas in the shape of the cross-section of a parabolic reflector (fan blade type antennas) and antennas with cosecant-square radiation characteristics at two different frequencies from a single antenna. For this purpose, firstly, a fan blade type antenna design will be made, and then the reflective surface of this antenna will be completed to the shape of the reflective surface of the antenna with the cosecant-square radiation characteristic with the frequency selective surface designed to provide the characteristics suitable for the purpose. The frequency selective surface designed and it provides the perfect transmission as possible at 4 GHz operating frequency, while it will act as a band-quenching filter for electromagnetic waves at 5 GHz operating frequency and will be a reflective surface. Thanks to this frequency selective surface to be used as a reflective surface in the antenna, a fan blade type radiation characteristic at 4 GHz operating frequency will be obtained, while a cosecant-square radiation characteristic at 5 GHz operating frequency will be obtained.

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1. INTRODUCTION

Antennas are devices that receive or emit electromagnetic waves. According to the way of using radio waves, antennas with receiver or transmitter characteristics can be mentioned [1]. Reflector antennas are frequently preferred in communication systems due to their narrow beam width and high gain radiation. The operating frequency of the parabolic reflector antenna made by Hertz is 450 MHz. It is not surprising that this antenna, which has a very low operating frequency compared to parabolic reflector antennas, which are frequently used at high frequencies in satellite communications today, has such a low operating frequency, considering the period it was built. Large parabolic reflector antennas are used to achieve high gain. When large-sized parabolic reflector antennas are positioned especially in windy places, their reflective surfaces are designed in the form of a grid. In this way, while increasing the resistance of the antenna against the wind, at the same time, its weight gets reduced. This reflective surface in the form of a grid is quite similar to the half-wave dipole array, which is one of the most well-known frequency-selective surfaces [2]. Frequency selective surfaces are structures consisting of periodic conductive patches placed on a dielectric layer or periodic cavities opened on the conductive surface. These structures act like a frequency dependent filter for electromagnetic waves.

In other words, the transmission and reflection characteristics of the frequency selective surfaces change according to the frequency of the electromagnetic wave overlying it [3]. In the present study,

the reflector antenna in the shape of the cross-section of the parabolic reflector will be completed to the physical structure of the antenna with cosecant-square radiation characteristic with frequency selective surface (FSS), which has been designed in accordance with the purpose. The designed FSS will have a high transmission coefficient at 4 GHz operating frequency, while it will have a high reflection coefficient at 5 GHz operating frequency. In this way, while the waves at 4 GHz operating frequency coming from the feeding antenna pass directly through the FSS, the reflective surface will be in the shape of the cross-section of the parabolic reflector and the fan blade type radiation characteristic will be obtained. While the waves at 5 GHz operating frequency coming from the feed antenna are reflected from the FSS, the reflective surface will be in the form of an antenna with a cosecant-square radiation characteristic and thus cosecant-square radiation characteristic will be obtained. In the frequency-selective surface design, it is aimed that the bandwidth in the resonance frequency is quite narrow for the transmission coefficient S21 at the operating frequency of 5 GHz and the characteristic of the FSS is as independent as possible from the arrival angle of the wave.

In the range of (-50, 50) degrees of incidence, the transmission coefficient S21 is required to decrease to -10 dB or lower at 5 GHz operating frequency. The same conditions are aimed for the reflection coefficient S11 at an operating frequency of 4 GHz. If these theoretically determined conditions are met, the FSS layer will not have any effect on electromagnetic waves at 4 GHz operating frequency, but will act as an excellent reflector at 5 GHz operating frequency. In this way, while obtaining fan blade type radiation characteristic at 4 GHz, cosecant-square radiation characteristic will be obtained at 5 GHz. However, in practice, some small degradation is expected in cosecant-square and fan wheel type radiation characteristics since the designed frequency-selective surface will not be able to provide all the desired conditions perfectly.

2. MATERIAL AND METHOD

2.1. Recommended reflector antenna model

In this work, it is aimed to design a reflector antenna with desired radiation patterns at two different frequencies by using frequency selective surfaces. The radiation patterns aimed to be obtained in the study are the radiation provided by the fan blade type antenna with desired modifications from Moreira and Bergmann [4] and the radiation patterns provided by the antenna with cosecant-square radiation characteristic. The recommended model for the reflector antenna that can provide these two different radiation patterns at different frequencies is shown in Figure 1. The reflective surface of the 4 GHz operating frequency fan blade type antenna according to Moreira and Bergmann [4] will be completed by using FSS to the shape of the reflective surface of the antenna with 5 GHz operating frequency cosecant-square radiation characteristic designed according to Yurduseven and Yurduseven [5] as shown in Figure 2. The feeds of these two antennas designed and the dimensions of the reflective surface will be used in the new design. In this way, two different radiation patterns to be obtained at different frequencies from the newly designed antenna can be compared with the radiation patterns obtained from two separate antennas designed by [4], [5]. For these purposes, frequency selective surface design will be realized first, and then this FSS will be used in the new antenna model as a reflector as shown in Figure 1. It is expected that the frequency selective surface to be designed will show as good a transmission characteristic as possible for electromagnetic waves at a frequency of 4 GHz, while a very good reflection characteristic for electromagnetic waves at a frequency of 5 GHz. Thus, for the feed antenna radiating with 4 GHz operating frequency, FSSs do not show reflective properties, while obtaining a fan blade type antenna structure, FSSs for the other feed antenna radiating with 5 GHz operating frequency show a reflective feature and it is thought to be obtained [6], [7].

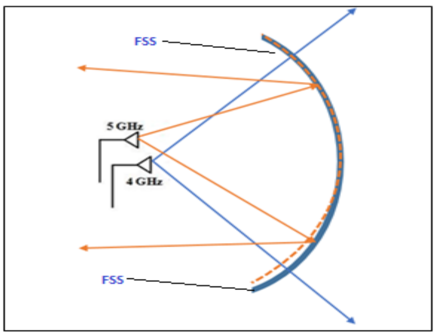

Figure 1. Geometry and operating principle of the reflector antenna with two different radiation patterns intended to be designed

2.2. FSS design for recommended reflector antenna model

Defining characteristics of the frequency-selective surface to be designed for the proposed reflector antenna model can be listed as [8], [9]:

a) FSS is expected to reduce the amplitude of electromagnetic waves transmitted at this frequency by at least 10 dB by showing band-quenching filter characteristic for S21 transmission coefficient at 5 GHz operating frequency.
b) FSS is expected to directly reflect the incoming electromagnetic wave at 5 GHz operating frequency without decreasing its amplitude by showing a very good reflection characteristic for S11 reflection coefficient.
c) FSS is expected to transmit directly the incoming electromagnetic wave at 4 GHz operating frequency for S21 transmission coefficient without any reduction in amplitude.
d) FSS is expected to reduce the amplitude of the electromagnetic waves reflected at this frequency by at least 10 dB by showing band-quenching filter characteristic for S11 reflection coefficient at 4 GHz operating frequency.

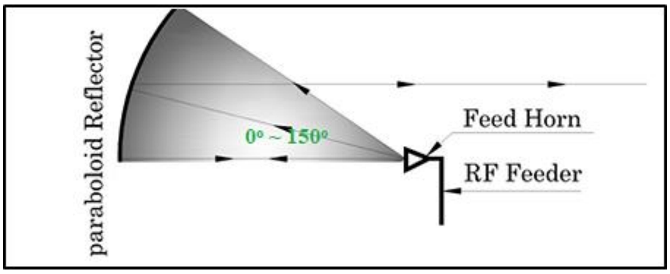

Figure 2. Maximum angle of arrival of the waves emitted from the feed antenna to the reflector [10]

As can be seen in Figure 2, the electromagnetic waves emitted from the feeding antenna reach the reflector with an angle of incidence of approximately 500 at the maximum slope and illuminate a large part of the FSS. Therefore, the frequency behavior of the FSS to be designed is expected to be as independent as possible in terms of the arrival of electromagnetic waves up to at least 500. Frequency selective surface designs and analyses made with different geometric shapes in line. These characteristics aimed for frequency selective surface structure will be shown in the next sections.

2.2.1. Frequency selective surface design using periodic square loops

In this section, the design and analysis of the frequency selective surface to be used for the proposed reflector antenna model with square loop element structure will be shown and the analysis results will be evaluated [11]. It is possible to think of a FSS as a surface architecture acting as a filter for plane waves at any angles of incidence. Broadband communications have made extensive use of it.

2.2.2. Geometry of the square loop structure

As a result of the optimization studies carried out in order to provide the intended characteristic features of the square loop shaped structure whose geometry is shown in Figure 3 [11]. The square loop FSSs in the literature have several forms. The geometric dimensions in which the frequency behavior closest to the requirements is obtained is a: side length = 20 mm; w: conductor path thickness = 1.5 mm and d: distance between periodic elements = 19 mm.

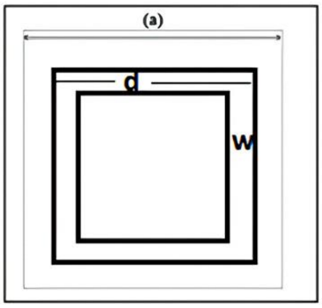

Figure 3. Geometry and dimensions of the square loop structure

The square loop structure shown in Figure 3 is defined as the perfect conductor perfect electric conductor (PEC) and modelled without thickness. Accordingly, the dimension of the geometry positioned on the XY plane in the Z-axis is assumed to be zero [12]. Periodic elements are defined as perfect conductors in order to obtain the analysis results of the designed frequency selective surface under ideal conditions. For this reason, it is aimed to shorten the simulation time by creating periodic element models in 2-dimensional form without thickness, since skin thickness (penetration depth) will not have an effect on the result in the analysis. In the high frequency structural simulator (HFSS) program, material is defined for 3-dimensional models with thickness, while boundary conditions are defined for 2-dimensional models without thickness. Accordingly, the boundary conditions for the surface of the designed 2-dimensional square loop shape were determined and these boundary conditions were set as perfect conductors. The structure in the form of a square loop, modelled without thickness in the XY plane, is analyzed as if it is an infinite periodic sequence along the X and Y axes, thanks to the boundary conditions defined in the HFSS program. The distance between periodic elements is determined during the design according to the element geometry and the distance between the planes where the boundary conditions are given [13], [14].

3. RESULTS AND DISCUSSION

3.1. Analysis and results of FSS designed using periodic square cycles

The geometry in the form of a square loop created with the measurements determined in the previous section was analyzed. The frequency-dependent variation curves of the FSS's S21 transmission coefficient for the waves coming in transverse electric (TE) mode at different θ angles obtained as a result of this analysis are shown in Figure 4. In the analysis, the angle value was chosen as zero.

In this section, it is explained the results of research and at the same time is given the comprehensive discussion. Results can be presented in figures, graphs, tables and others that make the reader understand easily [14], [15]. The discussion can be made in several sub-sections. The frequency-dependent variation curves of the FSS's reflection coefficient S11 for the waves coming in TE mode at different θ angles, obtained as a result of the analysis of the same geometry, are shown in Figure 5. In the analysis, the angle value of was chosen as zero.

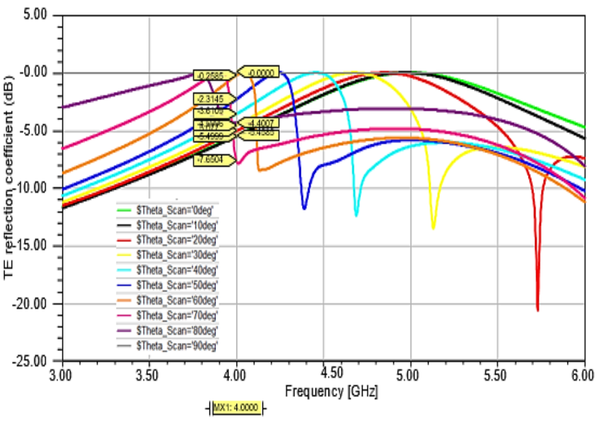

Figure 4. Frequency-dependent variation curves of the TE transmission coefficient for different θ angle

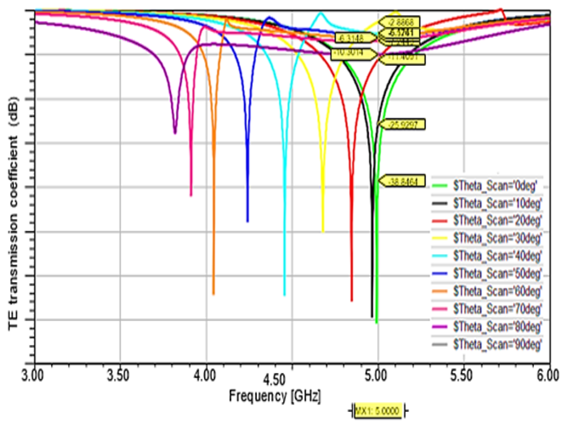

Figure 5. Frequency-dependent variation curves of TE transmission coefficient for the TE reflection coefficient for different θ angles

Resonance frequencies and bandwidths for -10 dB of the frequency-dependent variation curves of TE reflection coefficient at different angles shown in Figure 5. Figure 6 shows the frequency-dependent variation curves of the FSY's S21 transmission coefficient for the incoming waves in transverse magnetic (TM) mode at different θ angles. In the analysis, the angle value of was chosen as zero. Resonance frequencies and bandwidths for -10 dB of the frequency-dependent variation curves of the TM transmission coefficient at different θ angles shown in Figure 6.

Figure 7 shows the frequency-dependent variation curves of the reflection coefficient S11 of the FSY for the waves coming in TM mode at different θ angles. In the analysis, the angle value of was chosen as zero. Resonance frequencies and bandwidths for -10 dB of the frequency-dependent variation curves of the TM reflection coefficient at different angles shown in Figure 7.

Evaluation of analysis results: when the results obtained from the analyses were evaluated, it was seen that the characteristic features determined for the frequency-selective surface to be used in the proposed reflector antenna model could not be achieved. At least 10 dB attenuation, which was aimed for the transmission coefficient at 5 GHz operating frequency and for the reflection coefficient at 4 GHz operating frequency, could not be achieved at different angles. Since the frequency behaviour of the frequency selective surface is very sensitive to the angle of incidence and the bandwidths of the shown curves are high for -10 dB at the resonance frequency, it has been decided that this geometric structure is not suitable to be used in FSS design. As the desired frequency behaviours could not be obtained from the square loop structure, the three-legged structure was designed and analyzed, as it will be shown in the next section, with the thought that θ would be less sensitive to the angle of incidence and would have a narrower bandwidth at resonance frequencies [15].

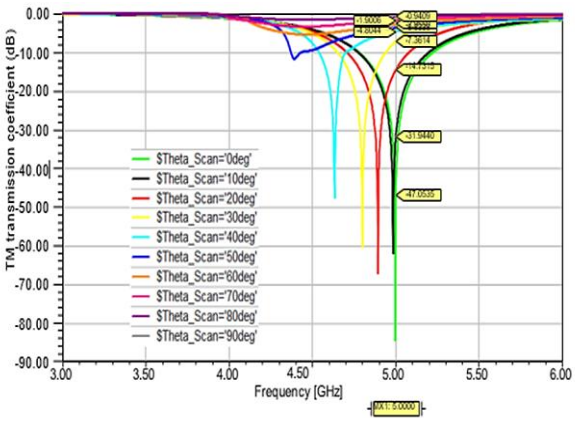

Figure 6. Frequency-dependent variation curves of the TM transmission coefficient for different θ angles

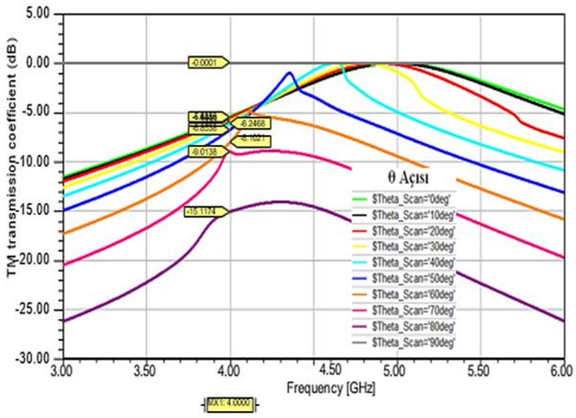

Figure 7. Frequency-dependent variation curves of the TM reflection coefficient for different θ angles

3.2. Design of the recommended reflector antenna model
3.2.1. Geometry of the proposed reflector antenna model

The design of the new reflector antenna model whose geometry and the analysis of the frequency selective surface to be used on the reflector surface is shown in Figure 8 solid works program was used in drawing the reflective surface due to the convenience it provides in drawing geometries. The reflective surface drawn with this program was converted into a suitable file format and transferred to the HFSS program. Then, the horn antennas drawn in the HFSS program and the reflective surface were brought to a suitable position and the analysis of the antenna was performed in the HFSS program [16].

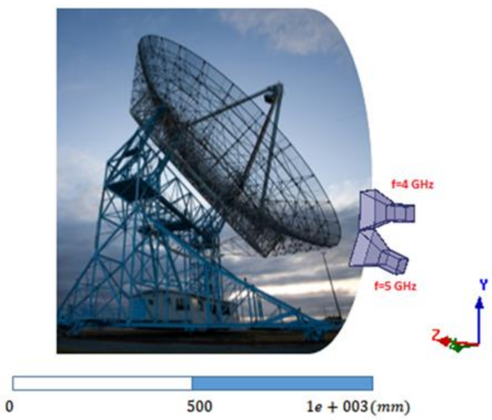

Figure 8. Schematic representation of reflector antenna model with two different radiation patterns designed

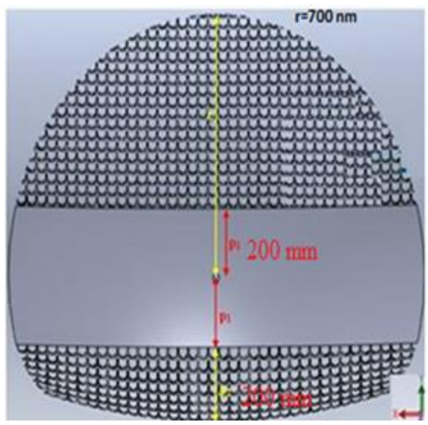

Figure 9. Reflective surface of the new reflector antenna with two different radiation patterns designed

The analysis results of the frequency selective surface designed and analyzed in the previous section show that this design largely meets the requirements for incoming electromagnetic waves in TE mode. For this reason, in order to obtain the desired correct results from the analysis of the new reflector antenna model in which this FSS structure is used on the reflector surface, the reflective surface is illuminated by electromagnetic waves with linear polarization and emitted by TE dominant mode [17], [18]. In the new reflector antenna shown in Figure 8 the horn antennas used as feeding antenna are identical. The cross section on the reflective surface of the designed new reflector antenna has been defined as the perfect conductor (PEC) and the dimensions of this surface are the same with the dimensions of the reflective surface of the fan blade type antenna model designed. The full dimensions of the reflective surface of the new reflector antenna together with the FSS structure are the same as the dimensions of the reflective surface of the cosecant-square radiation characteristic antenna model designed. Thus, as a result of the analysis of this new reflector antenna designed, the fan blade type radiation pattern and the cosecant-square radiation pattern were previously described. It can be compared with the radiation patterns obtained from two different antenna analysis in the literature [19]. Figure 9 shows the reflective surface of the designed new reflector antenna in more detail. The side view of the reflective surface of the designed antenna is shown in Figure 9. The lower part of the reflective surface of this antenna, which has the same dimensions with the dimensions of the cosecant-square radiation characteristic antenna designed also bent 400 towards the feeding antenna.

3.2.2. Analysis of the proposed reflector antenna model and results

The analysis of the reflector antenna with two different radiation patterns, whose geometry and design were shown in detail in the previous section, and the resulting radiation patterns will be shown in this section. From the analysis results obtained in in the previous section of the FSS structure used on the reflective surface, it is understood that this structure largely meets the requirements for the incoming electromagnetic waves in TE mode [5]. For this reason, in the analysis of the newly designed reflector antenna, the reflective surface was illuminated by electromagnetic waves with linear polarization and propagated by TE dominant mode. During the analysis performed at 4 GHz operating frequency, the other feeding antenna with a working frequency of 5 GHz was not considered as a model in the analysis, while the other feeding antenna with an operating frequency of 4 GHz was not considered as a model in the analysis during the analysis performed at 5 GHz operating frequency. In this way, the radiation patterns obtained by eliminating the possible distortion effects on the radiation pattern of the second feed, under the specified conditions [20], firstly, the new reflector antenna with two different radiation patterns was analyzed at 4 GHz operating frequency. The radiation pattern created by the antenna at this frequency is shown in Figure 10 and Figure 11. The image of the glow pattern shown in Figure 10 on the φ = 900 and φ = 00 planes is shown in Figure 12 and Figure 13, respectively.

As shown in Figure 12 and Figure 13 the antenna emits a narrow beam in one axis and a wide beam on the other axis. When these radiation patterns are compared with the radiation patterns of the fan blade type antenna is seen that they are substantially similar to each other. Especially with the radiation pattern in the φ = 00 plane. The radiation pattern of the fan blade type antenna on the same plane is very close to each other in terms of amplitude and shape. However, there are some minor differences between the radiation pattern in the φ = 900 plane and the radiation pattern in the same plane of the fan blade type antenna. The FSS structure, which causes weak reflections with small amplitudes at 4 GHz operating frequency, expands the reflective surface area that is included in the analysis in the 900 = 900 plane [21]. Therefore, the radiation pattern in the φ = 900 plane narrows due to the reflective surface area expanding in this plane. In addition, the FSS structure breaks the symmetry at the reflective surface at the = 900 plane. For this reason, due to the small amplitude weak reflections in the FSS structure at the 4 GHz operating frequency, small distortions occur in the symmetrical shape of the radiation pattern in the φ = 900 plane. However, when the analysis results are examined in general, except for such small details, it is seen that the fan blade type radiation characteristic intended for the 4 GHz operating frequency has been obtained [22].

After the fan blade type radiation characteristic obtained by the analysis of the new reflector antenna with two different radiation patterns designed at 4 GHz operating frequency. The antenna was analyzed at 5 GHz operating frequency in order to create the second radiation pattern, which is the cosecant-square radiation characteristic to be obtained from the same antenna. The radiation pattern created by the antenna at this frequency is shown in Figure 14.

As seen in Figure 14 the designed new reflector antenna emits an asymmetrical radiation in the φ = 900 plane for 5 GHz operating frequency. When this radiation pattern is compared with the radiation pattern of the antenna with the cosecant-square radiation characteristic, it is seen that these two patterns are mostly similar to each other. However, small distortions occurred in the cosecant-square radiation characteristic in the φ = 900 plane, due to the inability of FSS to show perfect reflective properties at the operating frequency of 5 GHz. Especially in the cosecant-square radiation pattern, the radiation with an

amplitude of approximately 10 dB between 1200 and 1500 caused by the reflected waves from the inward bending part of the parabolic reflector is approximately the same as shown in Figure 14 due to the failure of the FSS structure in the designed new reflector antenna. It has decreased to 5 dB levels. However, when the analysis results are examined in general, it is seen that the koskant - square radiation characteristic aimed for the 5 GHz operating frequency has been obtained [23]. As a result, when the design of the proposed reflector antenna and the results obtained with the analysis of this design are examined, it is seen that the intended data have been reached, except for small distortions caused by the FSS's failure to show the desired frequency behaviors perfectly. As can be seen from the radiation patterns formed as a result of the analysis, with the newly designed reflector antenna model, the fan-wheel type radiation characteristic at 4 GHz operating frequency was obtained, while the cosecant-square radiation characteristic was obtained at the operating frequency of 5 GHz [24], [25].

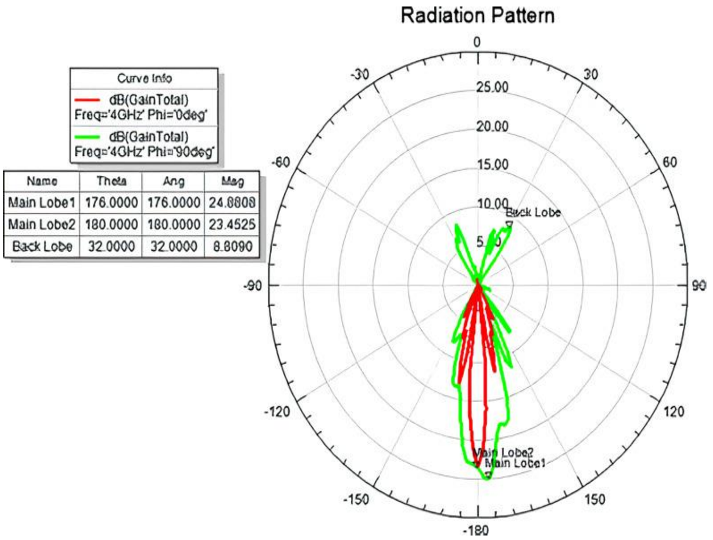

Figure 10. Radiation pattern of the designed new reflector antenna at f = 4 GHz operating frequency depending on the angle θ for = 00 and φ = 900

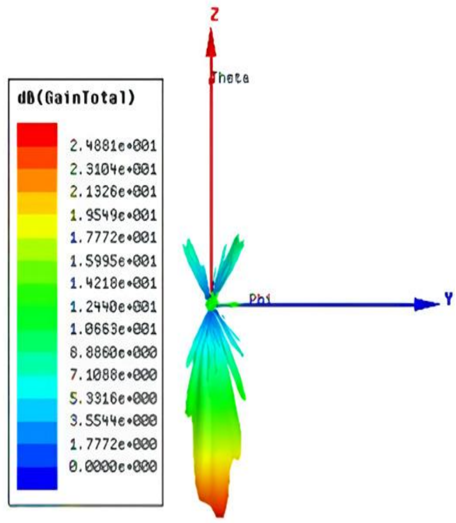

Figure 11. Radiation pattern of the newly designed reflector antenna at f = 4 GHz operating frequency

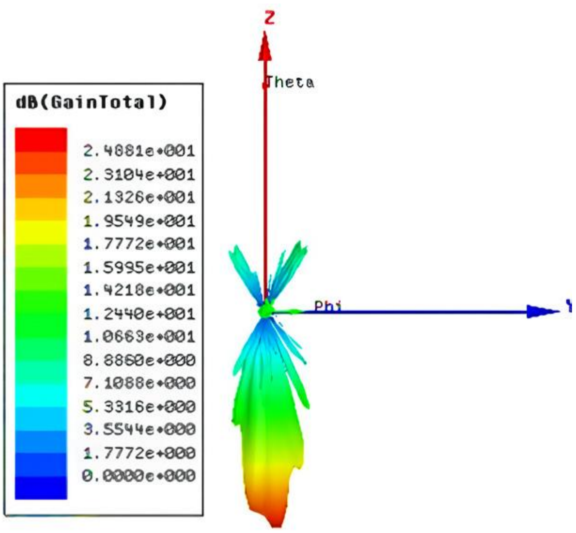

Figure 12. The image of the designed new reflector antenna at the f = 4 GHz operating frequency in the = 900 plane

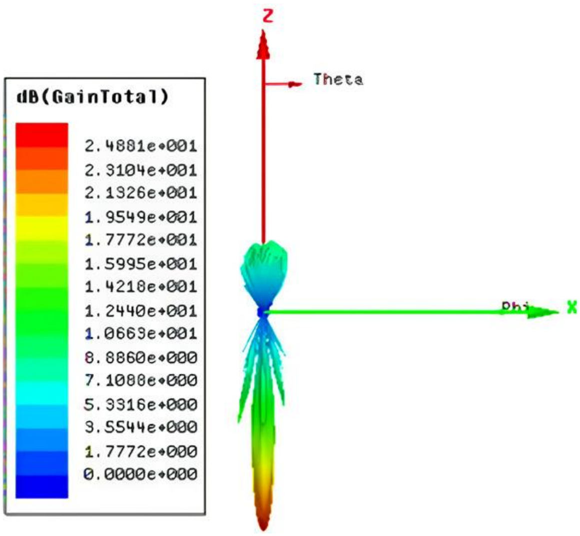

Figure 13. The image of the designed new reflector antenna in the = 00 plane of the radiation pattern at f = 4 GHz operating frequency

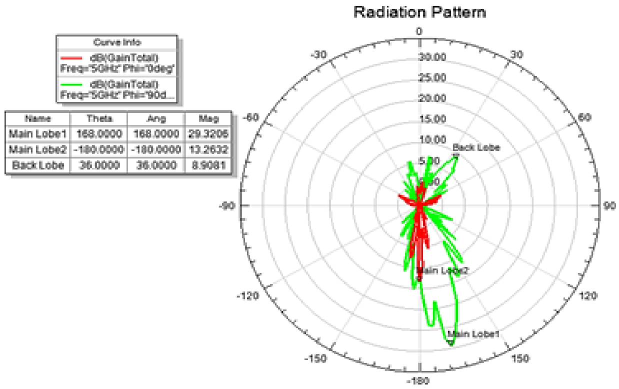

Figure 14. Radiation pattern of the designed new reflector antenna at f = 5 GHz operating frequency depending on the angle θ for = 00 and φ = 900

4. CONCLUSION

In this study, a fan blade type radiation pattern, which is two important radiation patterns commonly used in radar systems, and a reflector antenna model that can provide the cosecant-square radiation characteristic at two different frequencies is proposed and this antenna has been designed. Afterwards, two parabolic reflector antenna based antenna fan blade type antenna and cosecant-square radiation characteristic antenna were designed separately and the analysis results were examined. The errors of the HFSS program, which gives reliable results for plane FSS structures in FSS analyses, have been neglected during the antenna analysis for the FSSs that are inclined on the reflective surface of the antenna. In the newly designed reflector antenna model, two feeding antennas are used to provide two different frequencies of radiation. The feeder antennas used are identical, broadband horn antenna, and therefore produce a uniform radiation at both selected operating frequencies.

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